LASER MODULATION AT THE ATOMIC LEVEL

Monthly Report No. 1

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National Aeronautics and Space Administration
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GENERAL DYNAMICS | ELECTRONICS

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LASER MODULATION AT THE ATOMIC LEVEL

Purpose

Research on methods of influencing internally the radiating centers of active laser materials in order to achieve laser modulation is the principal objective of the work carried out under this contract.

Summary

An empirical method of obtaining the optical gain as a function of magnetic field for magnetic field modulated ruby lasers is discussed. Preparation for the experimental measurements has begun.

Man-Hours Worked

The total number of man-hours worked during the reporting period is: 371.5 hours.

TECHNICAL

Introduction

The initial phase of this study is concerned with the characterization of pulsed ruby lasers modulated internally by a time-varying inhomogeneous magnetic field. The inhomogeneous magnetic field interacts with the Zeeman components of the laser transition to modify the line shape including line width, and thereby the optical gain. Modulation of the ruby laser emission results. The modulated emission will be investigated for its amplitude, frequency, and spatial distribution. Observations on the reduction of super-radiance by the magnetic field are also planned. Basic to a correlation of this phenomena is a detailed knowledge of the instantaneous optical gain as set by the controlling magnetic field. Accordingly the effort in the present period has been devoted to preparations for the experimental determination of the absolute value of optical gain in ruby lasers as a function of inhomogeneous magnetic field intensity.

Method for Measuring Dependence of Gain on Magnetic Field

The approach that has been chosen for measuring the dependence of gain on magnetic field uses threshold for laser oscillation as the criterion for showing that a gain sufficient to overcome cavity losses has been achieved. Since the cavity losses are independent of magnetic field, threshold provides a fixed gain reference point. We can write the threshold gain condition in the form:

$$\frac{1}{2} \ell n R_1 R_2 \simeq \int_0^L \left[\sum_{i=1}^{N} \sigma_i (n_u - n_\ell)_i \, g(\nu - \nu_i)\right] dx, \qquad (1)$$

where the left-hand term gives the attenuation due to absorption and transmission through the end coatings, R_1 and R_2 being the end surface reflectivities, and the right-hand term gives the gain due to stimulated emission or absorption of the N transitions which have appreciable intensity at wavenumber ν , where σ_i is the absorption cross section for a transition from state ℓ to state u, n_ℓ and n_u are the concentrations of ions in the lower and upper state of transition i, respectively, and $g(\nu - \nu_i)$ is the normalized spectral shape factor for transition i. The integral is taken over the length L of the active laser medium. For pink ruby the equation can be simplified because only the ground state and the ^2E excited states have appreciable population densities under normal pumping conditions. The concentration of ions in these states of ruby at a temperature T between liquid nitrogen (77 °K) and ambient (300 °K) is well represented by:

$$N_o = 4n_1 + 2n_2 + 2n_2 e^{-\left(\frac{1.44\,\Delta\nu}{T}\right)}, \tag{2}$$

where N_o is the total concentration of Cr^{3+} ions, n_1 is the concentration in each of the four sub-levels of the ground state, n_2 is the concentration in the two sub-levels of the $\bar{E}$ state, and $\Delta\nu$ is the wavenumber difference between the $\bar{E}$ and $2\bar{A}$ levels (~ 29 cm^{-1}).

We note that only the gain at the R_1 line is responsible for laser oscillation, so that all the terms in the summation of Eq. (1) contain the same factor $(n_1 - n_2)$, which can be removed from the integration to give the expression:

$$\frac{1}{2} \ln R_1 R_2 \simeq (n_1 - n_2) \int_0^L \left[\sum_{i=1}^{8} \sigma_i\, g(\nu - \nu_i)\right] dx = (n_1 - n_2)\, \beta(H). \tag{3}$$

The integral $\beta(H)$ can be calculated from the Zeeman spectroscopic data if the line shapes $g(\nu - \nu_i)$ are known reasonably accurately. Alternatively, by using Eq. (3), the integral can be evaluated experimentally by measuring $(n_1 - n_2)$ at threshold as a function of the magnetic field. We propose to accomplish this by measuring the bleaching of the ground state absorption in the broad absorption band at 5500 Å. This broad band is not influenced by magnetic fields of the intensity utilized for this experiment. If we measure both the intensity I of a short probe pulse transmitted through the ruby when it has not been optically pumped, and the transmitted intensity I_p in coincidence with laser emission at threshold, $(n_1 - n_2)$ can be calculated from the relationship:

$$(n_1 - n_2) = \frac{N_o}{4}\left[1 - \frac{1}{\alpha_o L} \ln \frac{I_p}{I} \left(1 + \frac{2}{1 + \exp(-1.44\,\Delta\nu/T)}\right)\right],$$

where α_o is the unpumped linear absorption coefficient. By using a ruby with one end coated for high reflectivity at the laser wavelength and the other end uncoated, the loss will be dominated by transmission out of the uncoated end, which is known quite accurately. The parameter $\beta(H)$, which characterizes the gain modulation of the ruby by the inhomogeneous magnetic field, can thus be obtained from experimental measurements.

Experimental

The cavity in which the laser crystal is optically pumped and subjected to a magnetic field is shown in Fig. 1. The ruby rod is held by an evacuated stainless steel tube inside a dewar tube through which cold liquid nitrogen vapor is passed. Both ends of the ruby may be observed through windows on the dewar. The pump light is supplied by a linear flash lamp located at one focus of a polished elliptical cavity, the ruby being located at the other focus. A single turn coil for producing the inhomogeneous magnetic field enters the cavity from the side and is positioned coaxially with respect to the ruby rod.

The optical bench for making the transmission measurements is shown schematically in Fig. 2. The probing light is provided by a xenon flash lamp and is focussed onto a pinhole aperture by a condensing lens. The image of the pinhole in turn is focussed at the center of the ruby by lens 1. Before entering the ruby, a portion of the light is reflected by a beam splitter into a light pipe to a photomultiplier for monitoring purposes. Light leaving the ruby is focussed by lens 2 onto a screen with a hole in it (the proper positioning of the hole is to be described). The probe light passing through this hole is collimated by lens 3 and lens 4 (actually a Barlow eyepiece), and is reflected by a mirror to a second optical bench where a 60° prism and a cylindrical lens form a spectrum from which the desired wavelength is allowed to fall on the entrance slit of a monochromator. The output light from the monochromator falls on a photomultiplier. The additional spectral rejection given by the prism insures that the laser light does not enter the monochromator.

The positioning of the collimated probe beam is accomplished by substituting a continuous light source for the pulsed flash lamp, and by using a second lamp at the exit aperture of the ruby. Light from this latter lamp, after passing through the second beam splitter, illuminates the ruby. With this arrangement the image of the ruby on the first screen appears red, and the image of the probe beam white. The image of the ruby on the second screen is white and the probe beam red. The first pinhole is laterally and vertically adjustable, thus permitting the probe beam to be placed anywhere on the face of the crystal. The diameter of the probe beam may be adjusted to as small as one-tenth the diameter of the ruby. After the probe beam has been adjusted, the second screen with the aperture is placed so as to pass the image of the probe beam. This system is so effective in rejecting laser pump light that no pump light is visible on the signal from the output photomultiplier.

Electronic circuitry, block-diagrammed on the sketch, permit the magnetic field, pump flash lamp, and probing lamp to be pulsed in the desired sequence. In this way, the intensities I and I_p of a short probing pulse of monochromatic light transmitted through the unpumped and pumped ruby, respectively, for various magnetic field conditions at laser threshold may be obtained. The unpumped linear absorption coefficient α_o will be obtained in a separate measurement on an uncoated window cut from the same boule as the laser rod. Combining the quantities I, I_p and α_o, the threshold population inversion $(n_1 - n_2)$ and the parameter $\beta(H)$ may be found as a function of magnetic field intensity.

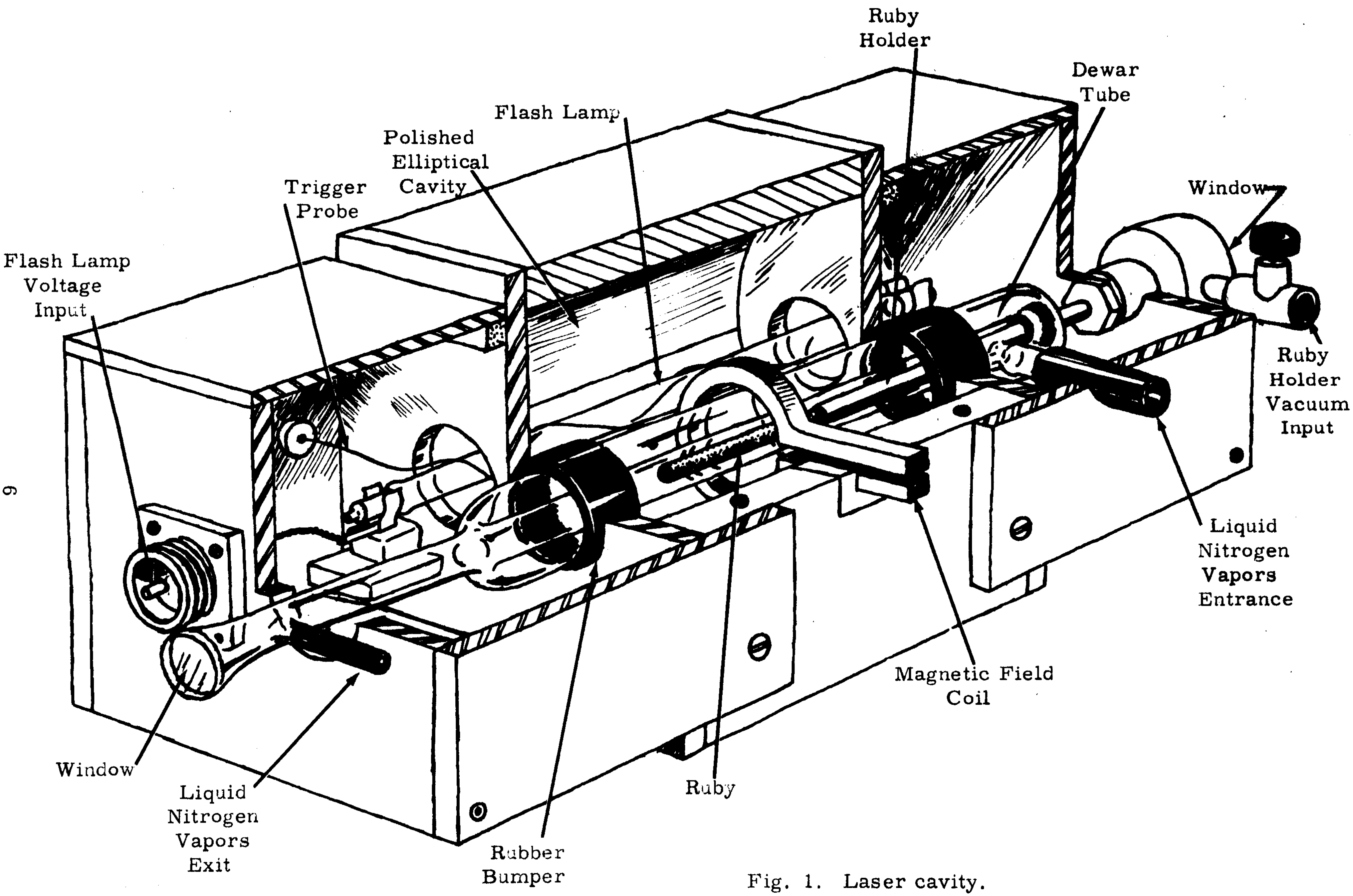

Fig. 1. Laser cavity.

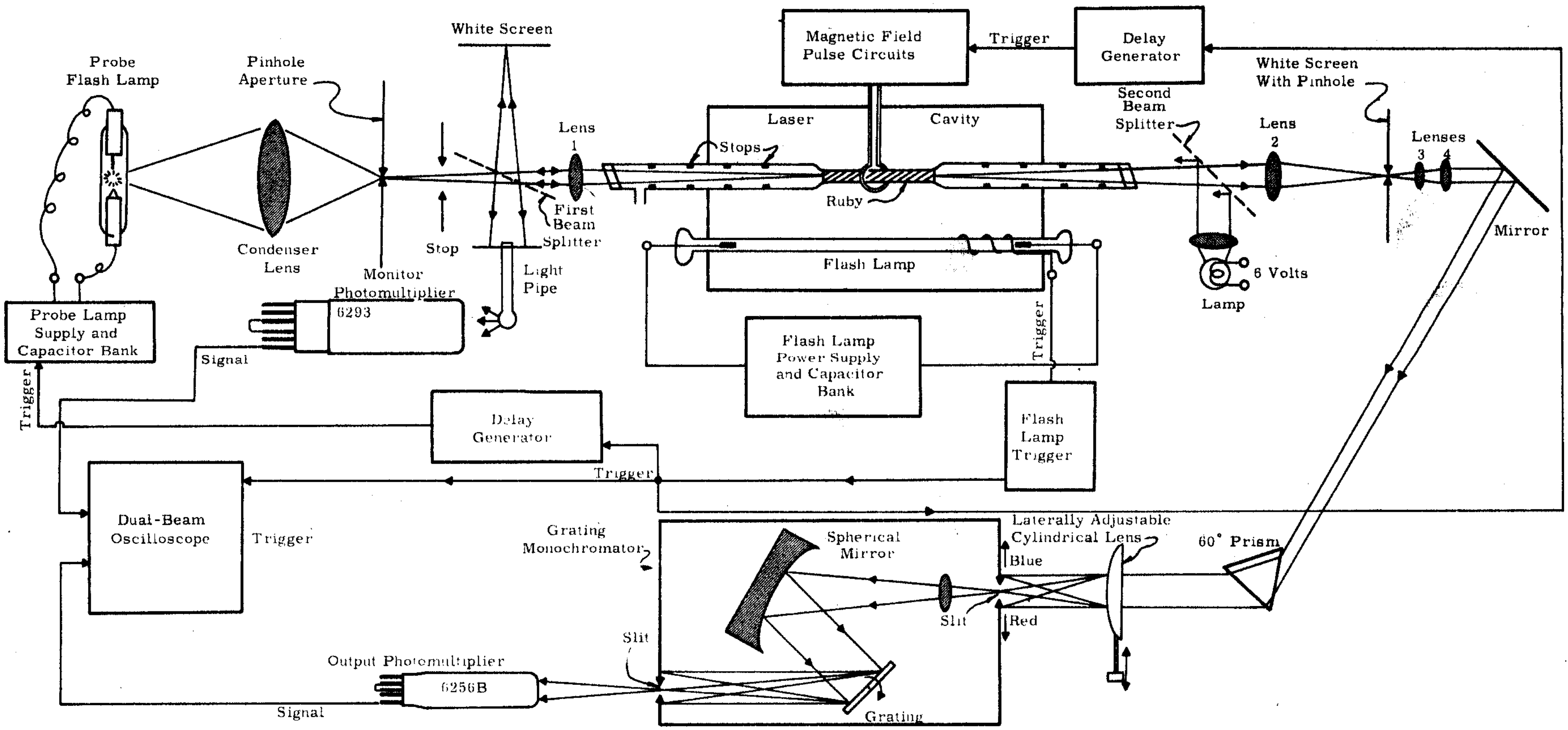

Fig. 2. Optical bench for transmission measurements.